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RESEARCH PAPER

Evaluation and classification of residential greenbelt quality based on factor analysis & clustering analysis: An example of Xinxiang City, China

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Abstract: Five factors expressing greenbelt quality and one factor expressing quantity were adopted for evaluation of the residential greenbelt, and the AHP (Analytical Hierarchy Process) method was used to determine the value of factors. Thirty residential areas were selected as the samples. Two principal components were extracted and their expression was constructed by method of factor anlysis, therefore, quality evaluation of residential greenbelt was obtained. The accuracy of the function and implement quality classification toward the residential greenbelts in Xinxiang City were validated by clustering analysis method. The results showed that the greenbelt quality of fourteen residential areas was higher than the average level, of which eleven were newly-built residential areas. The 30 residential areas were classified into three types according to their greenbelt features and their formation by clustering analysis method. Finally rational proposal basing on aforesaid evaluating results was proposed for construction and renewal of residential greenbelt, upon which directive basis was provided for construction and renewal of residential greenbelt.

Keywords: residential area; greenbelt quality; evaluation; factor analysis; clustering analysis

Introduction

It has all along been an exploring topic for numerous scholars on how to evaluate and compare quality of residential greenbelts (Galster 1981; Amérigo, et al. 1990; Van Poll 1997; Bonaiuto, et al. 1999). Quantitative evaluation, as one type of scientific effective method, is often used in research relevant to satisfaction degree evaluation toward residential environment (Adriaanse 2007), senior citizens' satisfaction degree evaluation toward residential areas (Fermina et al. 2001) and scenic beauty level evaluation for vegetation. The SBE(Scenic Beauty Estimation) method (Daniel et al. 1976) is mostly used in research of residential greenbelt quality in China about instance scenic beauty level evaluation for residential greenbelt (Zhou et al. 2006) and scenic beauty level evaluation for vegetation (Luo et al. 2005). In Code of Urban Residential Areas Planning & Design (GB50180－93 2002 revision), the residential greenbelt coverage ratio should not be less than 30% in China. The Guidance Rule for Design of Residential District Environmental Landscape (the draft edition) promulgated by the Ministry of Construction of China attempts to regulate qualitative requirements through its instructional principles. Consequently how to combine such quantitative and qualitative requirements perfectly and adopt a type of scientific accurate method to fulfill comprehensive assessment has become a worthwhile research subject.

Data procurement

There are many factors influencing quality of urban residential greenbelts. For simplified model, factors mutually owned by different residential areas can reflect their substantive characteristics. For qualitative measurement in our research, five factors (consisting of vegetation landscape x_1, place landscape x_2, hard landscape x_3, shelter landscape x_4, lighting landscape x_5) have been chosen as the variables hereby**.** All the factors must be considered in the building greenbelt in residential areas, while each of the factors comprises detailed criteria. The weight of a criterion is expertly valued by 1-9 and their reciprocals as basic scales with the AHP method and the correspondence test (C.R.<0.1) (Table 1)**.** The thirty residential areas were selected (consisting of $N_1－N_{15}$ newly built ones and $O_1－O_{15}$ previous ones) as the samples; Ten experts engaging in landscape planning & design would separately evaluate each factor index (x_{ij}) of the samples in range between 0 and 10. Then the evaluated value is multiplied by the weight-value for computing the mean value of the total value to acquire the value of factor (x_{ii}=1-5). For quantitative measurement, residential greenbelt coverage ratio (x_6) is used as the variables hereto (Table 2). For data processing,

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SPSS13.0 software is used.

Methods

The method of factor analysis is used to solve the problem of the multiple collinear-variables. The method of factor analysis should satisfy following conditions: comparatively higher correlation among factors; the ratio of sample size to variable size should be above 5:1; KMO （Kaiser-Meyer-Olkin Measure of Sampling Adequacy）should be above 0.5. The correlation analysis of several sample factor scores proves the high correlation between factors possibly because of the consideration for the balance of all factors in a residential green area during the landscape design. The ratio of sample size to variable size hereto is 5:1 and tested KMO is 0.817, all of which satisfy regarding requirements. Thus factor analysis is applicable hereby.

Table 1. Weight value of each factor index

Factor	Factor index	Weight	C.R.
Vegetation landscape (x_1)	Arbor coverage (x_{11})	0.3816	0.0389
	Species diversity (x_{12})	0.1853	
	Configuration diversity (x_{13})	0.3646	
	Native species proportion (x_{14})	0.0686	
Place landscape(x_2)	Function (x_{21})	0.558	0.0176
	Types multiplicity (x_{22})	0.122	
	Hhumanization (x_{23})	0.320	
Hard landscape (x_3)	Types all-sided (x_{31})	0.667	0
	Environment coordination (x_{32})	0.333	
Shelter landscape (x_4)	Function necessity (x_{41})	0.405	0.0279
	Modeling (x_{42})	0.114	
	Environment coordination (x_{43})	0.481	
Lighting landscape (x_5)	Safety (x_{51})	0.333	0
	Landscape effect (x_{52})	0.667	

Table 2. Factor values for quality evaluation of residential greenbelt

Sample	x_1	x_2	x_3	x_4	x_5	x_6	Sample	x_1	x_2	x_3	x_4	x_5	x_6
N_1	9.2	9	9.3	9.3	8.2	0.31	O_1	6.8	6.3	5.9	7.2	7.5	0.3
N_2	9.1	9.3	9.7	9.5	9.3	0.32	O_2	5.3	7.9	6.1	5.3	8	0.26
N_3	9.8	9.1	9.4	9.3	9.1	0.31	O_3	4.9	5.7	6.7	5	6.3	0.28
N_4	8.7	8.6	8.6	7.8	5.8	0.31	O_4	2.1	5.2	3.9	5.4	4.5	0.25
N_5	8.1	8.2	8.2	8.2	8.3	0.34	O_5	3	6.5	4.7	2.3	5.6	0.28
N_6	8.6	8.4	7.9	8.1	7.5	0.3	O_6	6.5	7.3	5.1	4.9	6.3	0.32
N_7	6.5	6.6	6.1	5.3	5.7	0.28	O_7	7.3	6.3	6.3	3.4	4.2	0.34
N_8	7.8	6.2	6.2	7.4	5.6	0.33	O_8	7	7.3	5.3	4.9	3.2	0.35
N_9	7.7	5.1	7	7.1	6.8	0.32	O_9	7.5	6.5	4.2	5.9	6.8	0.32
N_{10}	4.8	3.6	3.4	4.3	5.1	0.32	O_{10}	4.6	2.2	2.1	1.3	3.3	0.28
N_{11}	5.8	3.2	6.1	4.1	4.3	0.3	O_{11}	4.2	4	3.1	5.3	4.5	0.3
N_{12}	7.6	4.8	2.5	5.7	5	0.28	O_{12}	7.3	7.9	4.1	5.6	6.2	0.27
N_{13}	8.4	8.2	6.3	8.3	6.9	0.34	O_{13}	7.4	8.3	7.2	5.9	5.6	0.3
N_{14}	8.4	8.7	9.4	6.1	7	0.3	O_{14}	6.4	6.2	4.7	4.9	3.8	0.35
N_{15}	8.9	8.2	8.3	9.1	8.6	0.33	O_{15}	2.8	4.8	3.2	5.5	6.8	0.24

Results

Table 3 indicates that the eigenvalue of the first principal component is 3.957, which accounts for 65.95% of the total variation. Factor-loading matrix of the first principal component indicates that it plays a major role in reflecting qualitative factors consisting of vegetation landscape, place landscape, hard landscape, sheltering landscape and lighting landscape along with a very higher correlation coefficient. Characteristic root value of the second principal component is 1.109, accounting for the total variation by 18.479%, which indicates that it plays a major role in reflecting quantitative factor namely the greenbelt coverage ratio. The third principal component, though accounting for the total variation by 6.053%, only has the characteristic root value rather less than 1, which indicates that its accounting capacity is never so much as directly quoted initial variable. Since cumulative contribution ratio of the first and the second principal component accounts for approximately 85% hence, it is only necessary to extract the first and the second principal component. The expression involved in forming principal components by the factor-score matrix (Table 4) is:

$$f_1=0.083Zx_1+0.369Zx_2+0.22Zx_3+0.259Zx_4+0.246Zx_5-0.216Zx_6,$$
$$f_2=0.384Zx_1-0.324Zx_2+0.063Zx_3-0.023Zx_4-0.009Zx_5+0.747Zx_6 \quad (1)$$

where, f_1 is the first principal component, f_2 is the second principal component, $Zx_{i\ i=1\text{-}6}$ is the standardized factor score.

Table 3. Total variance explained

Component	Initial eigenvalues		
	Total	Percentage of variance	Cumulative (%)
1	3.957	65.950	65.950
2	1.109	18.479	84.429
3	0.363	6.053	90.481
4	0.221	3.691	94.172
5	0.202	3.362	97.534

Table 4. Component score coefficient matrix

Variable	Component 1	Component 2
x_1	0.083	0.348
x_2	0.369	-0.324
x_3	0.220	0.063
x_4	0.259	-0.023
x_5	0.246	-0.009
x_6	-0.216	0.747

Based on the variance contribution ration, the quality evaluation function of the residential greenbelt is as following:

$$F(x)=0.6595f_1+0.18479f_2. \quad (2)$$

When variables of the function are replaced by the standardized factor scores of greenbelt quality from the thirty residential areas, the scores of greenbelt quality and their ordination will be obtained (Table 5).

Table 5. Quality scores and rank list of each residential greenbelt

Sample	Component1	Component2	Synthesis	Rank	Sample	Component1	Component2	Synthesis	Rank
N_1	1.54070	0.23228	1.0590	3	O_1	0.40416	-0.37071	0.1980	10
N_2	1.80773	0.27088	1.2423	1	O_2	0.74143	-1.74725	0.1661	12
N_3	1.78632	0.16502	1.2086	2	O_3	-0.06233	-0.93734	-0.2143	19
N_4	0.68032	0.60684	0.5608	8	O_4	-0.64440	-1.93851	-0.7832	27
N_5	0.93757	0.78678	0.7637	5	O_5	-0.73366	-1.16298	-0.6988	25
N_6	1.06652	-0.02106	0.6995	6	O_6	-0.26422	0.32648	-0.1139	17
N_7	-0.03426	-0.56990	-0.1279	18	O_7	-1.04183	1.44638	-0.4198	21
N_8	-0.15576	0.95569	0.0739	14	O_8	-1.13091	1.79659	-0.4138	20
N_9	0.07931	0.47890	0.1408	13	O_9	-0.18154	0.36951	-0.0514	16
N_{10}	-1.32581	0.23851	-0.8303	28	O_{10}	-2.12068	-0.48666	-1.4885	30
N_{11}	-1.11452	0.12858	-0.7113	26	O_{11}	-1.18378	-0.29150	-0.8346	29
N_{12}	-0.68957	-0.34534	-0.5186	22	O_{12}	0.18862	-0.85569	-0.0337	15
N_{13}	0.46290	1.05218	0.4997	9	O_{13}	0.23777	0.14237	0.1831	11
N_{14}	0.88604	0.10541	0.6038	7	O_{14}	-1.22708	1.56484	-0.5201	23
N_{15}	1.23557	0.60019	0.9258	4	O_{15}	-0.14463	-2.54046	-0.5648	24

Notes: As parts of these residential areas are still for sale, the names of them are sheltered, whereas only those residential areas with higher scores are announced below.

Residential greenbelt quality classification basing on the method of clustering analysis

In the clustering analysis, unclassified data are ordered together based on the observed value or affinity of variables. The observed value is classified by successive polymerization. In this case, standardized variables are clustered by the fast cluster method to classify the residential areas into three types (Table 6).

Table 6. Cluster membership of residential greenbelt

Sample	Cluster	Distance	Sample	Cluster	Distance
N_1	2	0.702	O_1	3	1.728
N_2	2	1.202	O_2	1	2.150
N_3	2	1.125	O_3	1	1.246
N_4	2	1.290	O_4	1	1.744
N_5	2	0.938	O_5	1	1.591
N_6	2	0.755	O_6	3	0.951
N_7	1	1.374	O_7	3	1.431
N_8	3	1.144	O_8	3	1.771
N_9	3	1.490	O_9	3	1.161
N_{10}	3	2.000	O_{10}	1	2.960
N_{11}	3	2.002	O_{11}	1	1.587
N_{12}	1	1.777	O_{12}	1	1.838
N_{13}	2	1.449	O_{13}	3	1.661
N_{14}	2	1.449	O_{14}	3	1.441
N_{15}	2	0.748	O_{15}	1	1.826

Analysis and discussion

Ranking results of the factor analysis and sorting result of the clustering analysis indicate that both methods generate primarily the same result. Therefore principal component analysis and clustering analysis are scientific and reasonable methods in greenbelt quality evaluation of residential greenbelts.

Distribution of residential areas with different greenbelt quality

The greenbelt quality in 14 residential areas is higher than the average level of the whole, in which 11 residential areas are newly built, while 9 newly-built areas have the scores higher than 0.2, reflecting the increasing demand for greenbelt quality and general consideration to greenbelt build in new residential areas. The greenbelt quality of the Xinxiang City in the early-built residential areas is far from satisfaction.

Quality classification & characteristic features of residential greenbelt

The residential areas of grade I include N_1 (Jingu-Huating), N_2 (Huilong Sunshine City), N_3 (Jianye Green Home), N_4 (Bozhu-Zhengyang Garden), N_5 (Yiju University Town), N_6(Xinfei Garden), N_{13}(Xueyang Garden), N_{14}(Fenglin Garden), N_{15}(Chongming Garden), all of which have fairly good overall quality of residential greenbelt and comparatively higher green land coverage ratio. They have been paid much concern toward construction of eco-environment, places and sheltering landscapes. In addition, they have satisfied with demands of the general public toward top-grade night landscape.

The residential areas of grade II include N_8, N_9, N_{10}, N_{11}, O_1, O_6, O_7, O_8, O_9, O_{13}, O_{14}, all of which have comparatively higher greenbelt coverage ratio and good compatibility among all indexes reflecting qualitative construction.

The residential areas of grade III include N_7, N_{12}, O_2, O_3, O_4, O_5, O_{10}, O_{11}, O_{12}, O_{15}, all of which have rather lower greenbelt coverage ratio and greater diversity among each greenbelt factor.

Causes of classification

Causes of aforesaid classification are based on following conditions: 1). The general public has arisen higher and higher requirements toward environmental quality. For choosing dwelling places, greenbelt quality has been considered with priority, or even the first priority sometimes, which urged real estate developers to pay more concern toward greenbelt construction, not only in quantitative satisfaction but also in qualitative ground; 2). Construction quality of residential greenbelt is closely related to the design stage and the construction stage, particularly the design. Professional competence of designers impacts the residential greenbelt quality greatly. A senior designer should have paid

much concern toward the overall environmental factors of the residential greenbelt, while the initial residential greenbelt design schemes had unbalanced factors.

Model error analysis

For selection of evaluating indexes hereto, essential and significant factors generally recognized by general public and experts have been chosen. Other elements such as simulated landscape, water landscape and cultural landscape, etc. have not been reckoned in hereby for evaluation. The method of expert scoring has been used for obtaining factor values while accuracy of such value may be affected due to professional competence and vocational experience of such experts.

Suggestions for improving quality of residential greenbelt

Qualitative improvement of greenbelt

Under the condition of definite residential greenbelt coverage ratio, greenbelt quality can be improved only basing on qualitative ground. Demands of the general public living in the same residential area should be considered sufficiently in whole. Most crucial elements constituting greenbelt should be grasped overall to control their proportional relation. Secondary crucial elements constituting greenbelt should follow the principle of quality over quantity, intending to enhance the overall environment quality. In specific qualitative improvement can be fulfilled in following aspects: 1). A landscape designer should pay more attention to the ecological building of residential areas by applying lots of plant communities including good trees, especially those of the local flora; 2). Places of activities are most frequently used landscape elements for daily life of dwellers. Space, along with top-quality facilities, should be rationally organized on the basis of satisfied demands for acreage; 3). Sheltering landscapes should be provided to meet demands of all-weather use; 4). Sufficient concern should be given toward security of the residential areas; safety aspects related to traffic, plant, activities, apparatus, water landscapes, and electric energy consumption, etc. should be all-round considered. Design of lighting landscapes should satisfy security demands and build up overall landscape effects.

Quantitative improvement of greenbelt

For residential greenbelt construction, improving total size of residential greenbelt is the first target that should be considered with all priority. Our investigation and research demonstrated that greenbelt coverage ratios of newly built residential areas were barely higher than that of the national minimum standard. Motivated by economic benefits, real estate developers try best efforts to use land for housing construction. Greenbelt coverage ratios of early built residential areas were rather lower. Hence the total amount of greenbelt is very important in the building of greenbelt in residential areas. Its increase may produce an environmentally additional income, to some extent to balance the input of greenbelt building.

Construction of conservation-oriented greenbelt

Under the condition of definite economic investment, construction of conservation-oriented greenbelt is one of the important means to improve quality of residential greenbelt. In the building of greenbelt in residential areas, we suggest adopting the simple, natural and elegant style of landscape design, reducing complicated decoration and widely applying the technologies that can save land, energy, water and fertilizer. For example, the area of hard building with high unit cost in greenbelt as well as the lawn and water scenery with high unit cost of care could be used in the landscape planning. Acreage and quality of residential greenbelt can be effectively improved through construction of economy-oriented residential greenbelt.

Rational layout of greenbelt

The spatial pattern has important influence on the quality of greenbelt in residential areas. The practice show that the "concentrating combined with dispersing" layout in planning and design of residential greenbelt is suitable for meeting the demand of the public and providing the open space with high quality and ecological effect.

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